Annals of Arid Zone 48(2): 95-102, 2009

Controlled Environment Agriculture in Semi-arid North-West India

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Abstract: Harsh agro-climatic conditions in the arid north-west India, such as the Kachchh region permit only sparse agriculture with limited choices, low yields and high risk of crop failure. Excessive groundwater withdrawal combined with inadequate recharge is making irrigation expensive and in the long run unsustainable. Controlled environment agriculture can be a better and more sustainable way to make profitable horticulture possible in these areas. The outcome of one such initiative in which a special growing facility termed 'Arid Area Greenhouse' (AAG) was designed to grow vegetables in Kachchh region is discussed. AAG was developed keeping in view specific climatic and economic conditions - scarcity of water, hot winds, high levels of radiation, high temperatures, expensive and erratic power supply and only a low-end market nearby for fresh produce. Design goals of AAG were to create an environment favorable enough for plants to produce an economic yield, to make cropping possible also beyond the monsoons, to employ such methods of environmental control that economize water and electricity usage and to produce vegetables to be sold competitively in the local market. AAG consists of a greenhouse coupled to earth-tube–heat–exchanger (ETHE) in closed-loop and with additional provision for shading, natural ventilation and mist nozzles. It has been under investigation for over five years. It permits cropping over ten months (July-April), long enough to raise two crops. In open-fields here usually only one (monsoon season) crop is successful. Tomatoes have been raised over several rounds. In a recent round hybrid tomato yield was 68 t ha^{-1}, nearly two times that of the best yields on commercial farms in Gujarat. Water used in irrigation was 316 mm, nearly half of that in open fields. AAG holds promise as a new way to improve land and water productivity and raise vegetables in hot semi-arid regions.

Key words: Earth-tube-heat-exchanger, arid area greenhouse, arid area, tomato.

The Kachchh region of north-west India (22.5° to 24.5°N, 68.3° to 72.5°E) spread over 45,000 sq. km is divided in two parts (Fig. 1). The northern part - Great Rann - accounting for two-third of the area is entirely barren. It is characterized by high temperatures, high evaporation and wide occurrence of salt-crusted ground formed by recession of the sea. Temperature can go up to 50°C in summer. The southern part is inhabited. It is semi-arid characterized by wide occurrence of salt-affected soils, poor quality water, low and erratic rainfall (mean 300 mm, coefficient of variation 60%), high temperatures and radiation. It is also very windy. Cropping is successful only in monsoon season, with limited crop choices and low yields. In some locations groundwater is suitable for irrigation enabling farmers to grow cotton, groundnut and wheat. Water from these locations is also transported via tankers to villages that do not have own source of potable water. Excessive withdrawal and inadequate recharge of ground water is rapidly depleting these sources rendering irrigation energy-intensive, expensive and in the long run unsustainable. Agriculture will continue to remain sparse, low yielding and unstable.

Elsewhere semi-arid and arid areas, such as Arizona, southern Spain, parts of Negev desert area of Israel and Mexico, have become exporters of high quality horticultural produce by adoption of greenhouse technology. Abundant sunshine and mild winters in these regions offered potential for continuous production. Entrepreneur- growers recognized that potential and installed greenhouse centered production facilities. Local universities provided them the research and extension support and Industry the required equipment. Quality and freshness of the greenhouse produce competed favorably in the high-end markets of US, Canada and Europe, making horticulture in arid environment attractive and profitable business. Mears (1990) pointed to similar possibilities for arid regions of India. According to him, while a greenhouse is generally used to provide a warm environment in cold climates, it may be used to

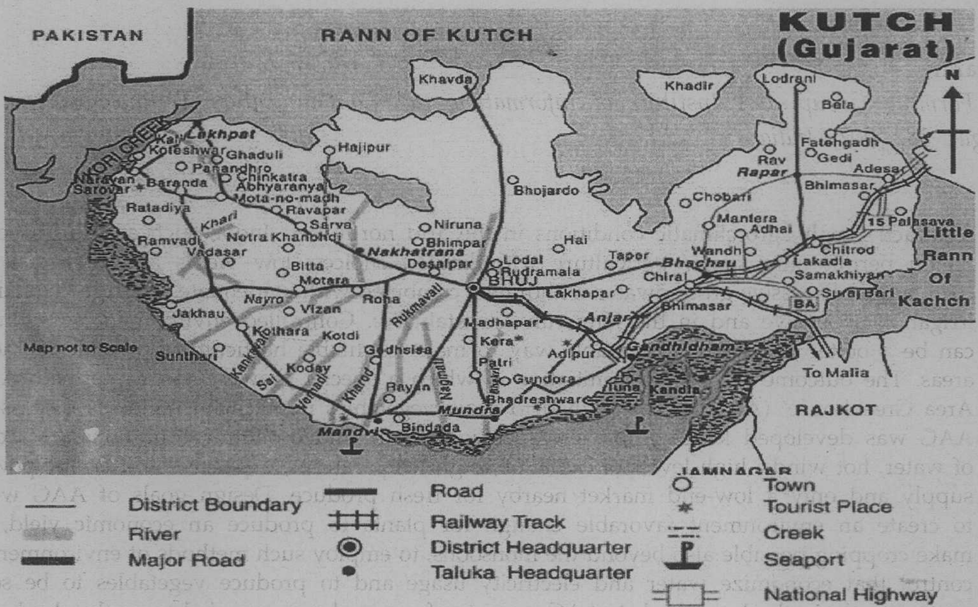

Fig. 1. Kachchh region north-west India.

improve plant growing conditions under extensively hot conditions. Adoption of modern cooling technologies will undoubtedly lead to increased opportunities for production of high value plants and materials in areas where the environment is extremely harsh. Protected cultivation also has the benefit of substantially increasing plant productivity per unit water consumed, which is important in areas where good quality water is severely limited.

Long hours of sunshine and mild winters in arid areas provide the basis for year-round production of plants. But environmental control of greenhouses in these regions can be an engineering challenge especially if water is scarce. It can also be a commercial challenge if a high-end market is not nearby where produce could be sold at a premium. Both these conditions occur in Kachchh region. Local populace and a large defense population constitute the market, which is high volume, but not a high-end type. That market is served by fresh produce transported from areas 500-1000 km away. The reason is that open-field cultivation in Kachchh area is risky, low yielding. It is only in small areas near Mandvi and Anjar that some vegetables and fruits are grown successfully. With proper environmental controls, greenhouses can improve and stabilize yields, extend growing season beyond monsoons, produce better quality and a wider variety of produce. With such greenhouses, growers can compete with transported produce in the local market. Some other conditions need also to be kept in view in designing controls. Electricity tariff is high and supply erratic. This would require that the environmental control measures use water and electricity economically and depend less on automation more on manual operation. Greenhouses for Kachchh region would not be high-tech type, but more of the type mentioned by Enoch (1986) that provide minimal climate control, enabling the plants to survive and produce an economical yield. More recently, Castilla and Hernandez (2007) also pointed out that in such (hot arid) regions it is the "shading effect" (reduction of solar radiation) during the high radiation season and the "windbreak effect" provided by the greenhouse, that is more important than the usual "greenhouse effect".

Keeping the above in view, a two-phase program was initiated in 1998 by the Centre for Management in Agriculture, Indian Institute of Management, Ahmedabad, to develop controlled environment agriculture for arid region of Kachchh. A centre was established at Kothara (23° 14′N, 68° 45′E). Goal of the first phase was to develop greenhouse for the regions that have relatively better quality water, focusing research on environmental controls, especially cooling. Second phase was to address the problem of desalination of brackish groundwater so that greenhouse cultivation can be extended to more difficult areas where water is brackish. Material presented here is drawn from the work of first phase of the ongoing program. First part of the presentation is assessment of environmental controls needed and selection of measures. The second part describes the details of AAG, the experimental facility developed for trial. Finally the performance of a recent tomato crop is discussed along with the performance of the environmental control measures.

Design Criteria of ETHE based Greenhouse for Kachchh

Temperature rise above ambient inside an unventilated, but well-watered greenhouse can be computed using equation 1 (Kittas, 1995):

$$\Delta T = \frac{0.017\,K + 2.64}{1 + 0.085\,u^{0.08}} \quad .....(1)$$

where,

ΔT = temperature difference between greenhouse inside and ambient (°C), K = global irradiance outside greenhouse (W/m^2), u = wind velocity measured at 4 m above ground (m/s)

Difference, ΔT, computed with global solar irradiance at noon (12:00) and mean daytime wind velocities measured at 4 m height at Kothara experimental site is shown in column 5 of Table 1. In December when day temperatures are near 32°C, an unventilated greenhouse will be hotter by 13.5°C, or at 45.5°C. Difference will be 16°C in spring, 17°C in summer and 15-17°C in fall. Clearly, the greenhouses will be overheated during the day in all months. Heating requirement is limited to December, January and February nights. Natural ventilation removes heat from inside without using energy. Reduction in ΔT due to ventilation can be computed using equation 2 (Kittas, 1995):

$$R = \frac{0.31\,K_{max}}{\Delta T} \quad .....(2)$$

where,

R =Rrenewal (air change rate) per hour, K_{max} = maximum global irradiance (W/m^2).

Assuming renewal rate of 40 per hour (plausible in coastal areas during day) in equation (2), ΔT works out to 5-6°C in December as shown in column (5). In warmer months of summer it will be 7.5°C. The reduction, largely due to wind, is significant, but it is only in December that this measure will keep the inside temperature from exceeding 32°C, commonly desired upper limit. It points to the need to reduce entry of heat into the house.

Cladding is the first barrier against entry of heat. Kittas *et al.* (1999) reported that in the waveband 300-1100 nm, total transmission of irradiance into a polythene covered tunnel was 0.65, in twin span glass house, 0.54 and multi-span fiberglass house 0.49. Shading devices can further alleviate heat load. Shading devices have several other positive effects on greenhouse microclimate (Baille *et al.*, 2001), such as increased transpiration rate, reduced crop water stress index and several others. Sharan and Chitlange (2004) made radiometric measurements on shade nets available in India, in 400-1000 nm range at 10 nm interval. Assuming a net of 50% effective shading is installed over polythene clad greenhouse with transmittance of 0.65 as in case of Kittas *et al.* (1999), the overall transmittance will be 0.325. With such shade net and natural ventilation, ΔT would reduce further as shown in column (5). Values are obtained using equation (2) with radiation level reduced to one-third of that in column (1) and renewals of 40 per hour as before. As shown in the last column (6) these two measures would keep the temperature below 32°C in August, December and slightly above it in September, November, January and February. This is an appreciable improvement, but more effective cooling will still be needed over six months.

Fan-pad method is the most common and also most effective. Others are sprinkling and fog. Estimate of the water consumption in hottest part of the year (June) in Kachchh area was made using accepted procedures, Indian Standard Code and also Nelson (1997). It worked out to 7 mm to 10 mm of water per day, with top shaded. It is comparable to crop water requirement. Data now available from elsewhere indicate that it could be even higher. Sabeh *et al.* (2006) measured water used at Tuscan, Arizona. When temperature of a 278 m^2 greenhouse with tomato inside was on automatic control mode to maintain 24°C/18°C day/night temperatures, cooling system used 14.8 L/m^2/day and crop 8.9 L/m^2/day. Sprinkling using wet blankets (Giacomelli *et al.*, 1985) and fog system (Arbel *et al.*, 1999, 2003) improved the uniformity of microclimate created, over fan-pads. High water consumption, however, is common feature of all forms of evaporative cooling.

It was decided to provide mist nozzles for occasional use, but not a full-fledged evaporative cooling system. Another device to mechanically remove heat from inside greenhouse and reject

Table 1. Irradiaton, temperature and wind velocity at Kothara experimental site

Month	Global solar irradiance at noon (w/m^2)	Mean 4 m wind velocity during day (m/s)	Range of normal ambient air temperature (°C)	Maximum temperature difference ΔT (°C)	Expected range with shade and ventilation (°C)
January	725	6.1	8-32	13.6-5.6-1.8	8-34
February	781	6.4	9-33	14.5-6.1-2	9-35
March	883	6.6	17-37	16.1-6.8-.2.2	17-39
April	914	6.4	20-37	16.5-7.1-2.3	20-39
May	952	8.7	21-36	17.1-7.4-2.4	21-38
June	962	8.5	20-35	17.3-7.5-2.4	20-37
July	658	4.5	25-33	12.6-5.1-1.7	25-35
August	842	8.0	27-33	15.4-6.5-2.1	27-35
September	948	7.0	23-32	17.1-7.3-2.4	23-34
October	827	5.5	19-40	15.2-6.4-2.1	19-42
November	746	5.3	15-31	14-5.8-1.9	15-33
December	678	5.6	7-27	12.9-5.3-1.7	7-29

Note: values shown in column 5 are temperature rise respectively in unventilated house, ventilated with 40 air changes/hr, ventilated with 40 air changes/hr and 50% shade.

it into constant temperature sink below ground is the ETHEs. Santamouris *et al.* (1995) reviewed eighteen greenhouse installations drawn from different countries using ETHEs. Most used these to supplement heating. Using simulated results for a greenhouse facility in Athens (37.5° N) they stated that ETHE would be an equally attractive supplement for cooling. Although no experience with ETHEs existed in India at the time, it was decided to try these out.

Environmental control of greenhouses in water-scarce and high cooling load areas is a challenge. Heating requirement is limited to the nights in winter months, while cooling is required through almost all months. Shading and natural ventilation are effective in cooler months. In warmer season evaporative cooling would be effective. But given its high water consumption, sustainability can become an issue. One way to improve cooling and yet use less water than the fan-pads could be to couple the greenhouse to an ETHE in closed loop and use mist nozzles to improve its effectiveness.

Arid area greenhouse

Based on the foregoing analysis, a new facility termed 'arid area greenhouse' was developed and installed at Kothara. Details can be seen in Sharan *et al.* (2003) and Sharan and Jethva (2008). It consists of a greenhouse connected to a ETHE and with additional provision for shading, natural ventilation and mist nozzles, vents, shade net. Greenhouse is a single span, saw-tooth structure (20 m x 6 m x 3.5 m) with floor area of 120 m^2 and volume 360 m^3. It is clad with 200 micron UV stabilized clear single skin PE film with transmittance of 0.8 (manufacturer's data). There are three 20 m x 0.5 m closable vents, two at the base of the side walls, third at the top of higher side (Fig. 2A). Vents are screened with commercially available stainless steel wire mesh -15 strands per inch in each direction and whole size less than 1 mm. Unscreened vent area was 25% of the floor area. A retractable shade net was put on top. Shade net was installed just above the cladding. Net used was green-black with shading of 50% (manufacturer data). There are 39 mist nozzles (manufacturers data operating pressure 4 kg cm^{-2}, discharge 0.007 m^3 hr^{-1}) installed 3 m overhead on a grid pattern.

The ETHE connected to the greenhouse provides air flow rate equivalent to 40 changes per hour. It is made of eight pipes that connect to identical headers on both ends (Fig. 2B). Pipes are of mild steel with 3 mm thick wall, arranged in two tiers. First tier is at 3 m, second at 2 m depth. Pipes are 23 m long, placed 1.5 m apart laterally. Air inside greenhouse is drawn, cycled through buried pipes and returned to the greenhouse. A centrifugal blower powered by 4 kW, 1440 rpm motor circulates the air.

An eight-channel data logger (from Weather Technologies, India) was used to record ambient temperature, global solar radiation, relative humidity, wind speed (three-cup anemometer) outside; and air temperatures at three locations, relative humidity at one location inside greenhouse. The outside temperature and humidity sensors were placed 2 m away from the greenhouse boundary and 1 m above ground. The anemometer and the radiation sensor were located 20 m away from the greenhouse over a roof of 5 m high building. There were four sensors inside, three for temperature and one for humidity, placed along the centre line 1 m above the ground and weather shielded. One temperature sensor was placed at west end, one in the middle and one at the east end of the greenhouse. The humidity sensor was

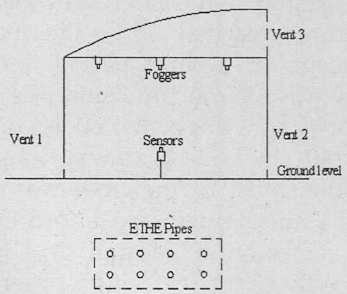

Fig. 2A. Schematic diagram of greenhouse.

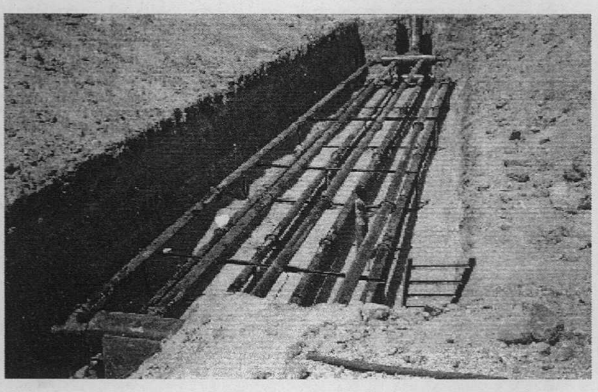

Fig. 2B. Earth tube heat exchanger before backfill.

placed at the middle also. Data logger had LCD display, real time clock calendar, and serial output port for connecting it to PC with parallel interface to printer or memory module.

Cropping in Arid Area Greenhouse

Cropping trials started in 2003 and are continuing. It is possible to raise crops over ten months from July to April. Initially it was tried to keep the cropping on through May and June as well. But the environment became too hot leading to fruits smaller in size and poor in quality. Two crops can be grown. Tomatoes, okra, chilly, capsicum (bell pepper) were tried in earlier rounds. Tomatoes have been grown over three rounds. Here the results of another round of tomatoes (hybrid US 1080) rose during October-April are discussed. Planted area was 96 m^2 with plants at 45 x 45 cm spacing. Plants were pruned and trailed. Picking began in January (97 days after planting) and continued through April. Fertilizer was applied in liquid form through drip line as per recommendation of the seed suppliers. Watering was done through drip.

Environmental control measures available were (a) Natural ventilation + shade net: Typically used in combination, although days in December-January usually do not need shade; vents were opened at 10:00 hrs and closed at 17:00 hrs. (b)Shade net + forced ventilation from ETHE : Employed for heating in December, January nights, shade net made heating more effective by working as night curtain, ETHE usually was operated from 22:00 hrs to 06:00 hrs. (c) Shade net + forced ventilation from ETHE: During day time for cooling in warmer season specially when tall and dense crop restricted natural ventilation. (d) Shade net + ETH: mist spray - usually needed March, April onwards; as stated in this round mist was not deployed.

During November and December measure (a) was implemented; from the fourth week of December through January, measure (a) in day time and (b) at night; February and March measure (a); April measure (c). Graphs showing temperatures inside greenhouse (mean of three locations) and the ambient are presented of a day in November, January, March and April. On November 21, a month after planting and with measure (a) in place the inside temperature raised to 33°C almost the same as ambient (Fig. 3). Mean RH during daytime was 54%. Wind varied between 3-5 m/s. That the greenhouse temperature did not exceed the ambient was surprising. Even with shade on and natural ventilation active, inside was expected to be ~ 2°C warmer (column 5 Table 1). As will be seen this behavior continues until March. It may be that evaporation from well watered ground contributes to some extra cooling. On December 22 (graph not shown) also the maximum temperature inside was equal to maximum ambient outside 31°C. Night temperature remained above 12°C. Mean RH was 59% during the day. On most days ventilation

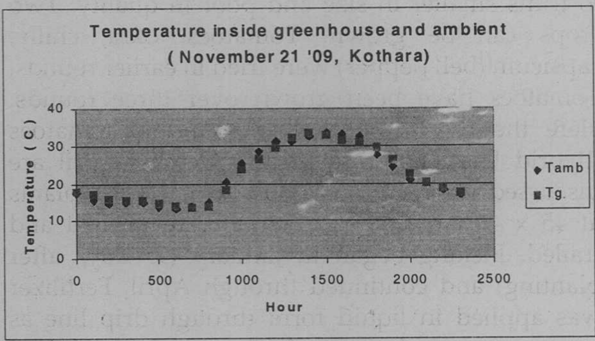

Fig. 3. Temperatures inside greenhouse (Tg) and ambient (Tamb).

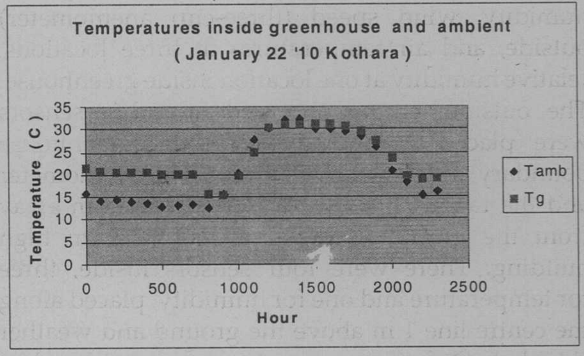

Fig. 4. Temperatures inside greenhouse (Tg) and ambient (Tamb) night Heating.

without shade was adequate to limit the inside to 32°C. Towards the end of December night temperatures began to fall further. Measure (b) was implemented at night and (a) during the day through January except when electricity was not available.

ETHE was on from 22:00 hrs of January 21 to 06:00 hrs of January 22. Before start of ETHE ambient temperature was 15.6°C, while inside greenhouse it was 16.3°C. By midnight the greenhouse temperature rose to 21°C (Fig. 4). Greenhouse was warmer than the ambient all through the night, being 19°C when ETHE was switched off. Average humidity inside greenhouse at night was 54%. Without heating, inside temperature would closely track the ambient, which fell below 13°C by 06:00 hrs in the morning. It was observed that the air entering the greenhouse from ETHE cooled by about 3°C as it moved through to exit.

Weather began to warm up in February. Night heating was no longer needed, but day temperatures begin to approach 35°C and higher later in March. On March 21 (Fig. 5) ambient temperatures reached 37°C, the inside was the same except for a short period. Mean day time humidity was 63%. A provision was made to raise humidity by spraying water once a day generously over a 100 cm wide walkway longitudinally in the middle. Most of the floor was covered with crop. This middle path did afford evaporation as by the afternoon it became dry. Mist was not used in view of the leaf injury observed in earlier rounds. Beginning April measure (c) was implemented – shade net and forced ventilation via ETHE. On April 29 (Fig. 6) the maximum inside temperature rose to 38°C when ambient temperature was 36.5°C and mean humidity 55%. Without ETHE operation inside temperature would be still higher than the ambient as was observed on May 2 when electricity was not available through out the day. Temperature inside greenhouse rose to 39°C, with a peak ambient of 35.2°C. Crop was removed soon after. It was observed that the temperature of air entering the greenhouse from ETHE rose by about 2°C as it moved through to the exit.

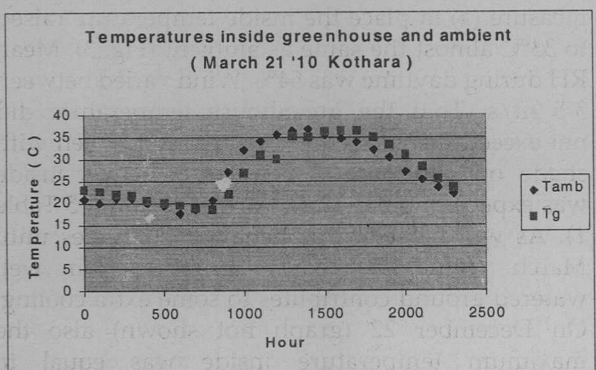

Fig. 5. Temperatures inside greenhouse (Tg) and ambient (Tamb).

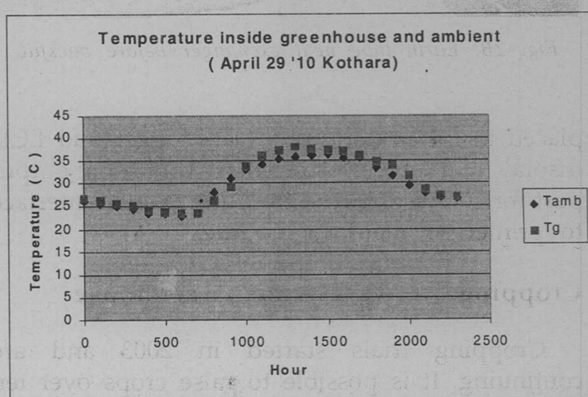

Fig. 6. Temperatures inside greenhouse (Tg) and ambient (Tamb).

Water applied was recorded using mean calibrated discharge of emitters and duration. Yield was 68 t ha^{-1}. Total irrigation water applied was 316 mm. No mist nozzles were used. Tomato is not grown commercially in the district. Some farmers do plant small areas for own use. Plants in the fields generally wither by the end of February. Estimates of yields and water usage based on interviews with the farmers suggest that water used in open-field is twice and yield nearly half that of the greenhouse.

The ETHE made of metal pipes was expensive. Also the present configuration (two tiers with common headers) makes it difficult to scale-up or augment its capacity. It would be desirable to use plastic pipes to reduce cost and make the design modular so that it could be fabricated, transported and installed easily in smaller units. Plastic pipes may also resist corrosion and help reduce fan power. During heating mode operations, the row of plants nearest the inlet was adversely affected leading to shedding of flowers. Placing a barrier of shade net between the plants and the inlet louvers reduced that adverse effect. In the present ETHE the inlet and outlet are on opposite ends of greenhouse, but at the same level. It would be better to place the outlet at a higher level. Such an arrangement would readily draw warm air out and make environment uniform.

Conclusion

Open-field crops in the vast semi-arid region of Kachchh in the north-west produce low and unstable yields with limited choices. A wider variety of vegetables can be produced on steady basis with higher than the open-field yields and lower water consumption in suitably designed greenhouses. Greenhouse with provision of earth-tube-heat-exchanger, natural ventilation, shading and of occasional use mist nozzles, made it possible to carry out cropping through spring and early summer. Single crop yield of hybrid tomatoes in season October-April yielded 68 t ha^{-1} and used 316 mm water for irrigation. Water used in open-field in this area would be twice as much and crop yield less than half.

Shading and natural ventilation kept the greenhouse temperature close to 32°C from November to January, below 35°C in February and part of March. Shading and forced ventilation via the ETHE kept the greenhouse temperature below 38°C till the end of April. Without the latter temperature would have risen to 39-40°C. There is need to reduce the initial cost of ETHE, which presently uses metal pipes involving heavy fabrication cost. The present configuration also does not lend itself to augmentation and scale-up.

Acknowledgements

We thank the World Bank for funding, the Gujarat Energy Development Agency, for providing the land for experimentation and the Indian Institute of Management for facilities. Engineers, Sanjay Kumar and M.P. Chandra provided research assistance. Dr. Piyush Pande read the final draft and suggested improvements.

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